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AIRCRAFT FIRE PROTECTION FOR HELICOPTER GAS TURBINE POWERPLANT AND RELATED SYSTEMS INSTALLATIONS

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PREFACE

This document was issued in 1963 by the Powerplant Installation Committee of the Aerospace Industries Association (A.I.A.) as a design manual for all types of aircraft: "Aircraft Fire Protection for Reciprocating and Gas Turbine Installations. Aerospace Industries Association." (Aug. 1, 1949. Revised 1963). Since then the originating Committee was dissolved and the manual became unavailable. In this period, advancements in aircraft fire protection methods have been produced by both governmental and private agencies that are not reflected in the original manual. Recognizing this, the SAE S-12 Helicopter Powerplant Committee has prepared this revision as an AIR (Aerospace Information Report) to bring it up to date and to emphasize helicopter turbine powerplant fire protection, excluding previously included airframe-related items such as brakes, wheels, baggage compartments, cabins, etc.

PURPOSE

This design manual contains fire-prevention information accumulated on civil and military aircraft. It is presented as a service to all organizations, government agencies, and individuals interested in aviation as well as to the helicopter designer, to whom the information is specifically directed. This material has been presented in concise indexed form to serve as generalized reference material and to provide background data for the designer. It is not intended that this be considered as proposed regulatory or specification material because it borders on maximum rather than minimum required airworthiness.

The AIA Manual was first published 1 August 1949. It was previously revised on 15 April 1954 and 1 December 1957 and, in that time, has been used widely as a guide by many government and civil organizations of both domestic and foreign countries in the manufacturing, operating, and educational fields of aircraft. This revision incorporates the experience of individuals from many helicopter airframe, and engine companies, and from several government agencies.

The following government publications were used as a guide to fire protection requirements in preparation of this manual:

- A. Air Force Systems Command Design Handbook 2-3, Propulsion and Power (Ref. 1).
- B. U. S. Navy Specification SD-24K, "General Specification for Design and Construction of Aircraft Weapon Systems", Vol. II, Rotary Wing Aircraft (Ref. 2).
- C. Federal Air Regulations - Part 29 - Airworthiness Standards: Transport Category Rotorcraft (Ref. 3).
- D. MIL-HDBK-221 (WP) "Military Standardization Handbook-Fire Protection Design Handbook for U. S. Navy Aircraft Powered by Turbine Engines" (Ref. 4).

SCOPE

This document is reissued for application to helicopters. It is primarily intended to apply to the engine or engines, but it shall also apply to fire protection of lines, tanks, combustion heaters, and auxiliary powerplants (APU). Post-crash fire protection is also discussed.

INTRODUCTION

The work done in the initial stages of design will determine the final degree of fire protection inherent in a new helicopter; therefore, considerable foresight as to the eventual installation details is necessary. A lack of perception as to the relationship between a source of ignition and combustible fluids or materials may result in a combination which no amount of subsequent detailed design struggling can ever completely remedy. The inevitable design conflicts which arise on any new helicopter, and the resultant compromises, should always consider the fire potential in order to obtain a sensible balance. For this reason, emphasis to keep the thought of fire protection prominent in preliminary design work is well worth the effort. The following design points are intended to give a number of general rules for the fire protection features of preliminary design. If fire protection is considered in the preliminary design, the work of the detail designer trying to protect any particular section of the helicopter from the hazards of fire can be greatly simplified.

Each helicopter is an individual problem and it is realized that many factors will affect the decisions in its design. However, the nearer the design can be to basic safety principles, the less will be the chance of trouble caused by detail design errors, maintenance in the field, or failures of equipment. It is strongly felt that the basic safety responsibility for a helicopter lies on the drawing board. Each engineer concerned with the design of a system or component should realize its potential relation to all other affiliated and adjacent items and to the helicopter as a whole. Because the most important phase of fire protection is the prevention of occurrence of fire, each engineer responsible for the design of a component of a helicopter can contribute most satisfactorily to the basic safety of the helicopter if he has a thorough knowledge of the aircraft fire protection problem. Therefore, this AIR is built around a general discussion of fire protection. Mention of specific systems is made only where the general discussion does not apply, or where exceptions to the general discussion must be pointed out.

Regardless of the original fire protection design features built into the helicopter, it is necessary to maintain the helicopter properly to avoid increasing fire hazards; various means and procedures for accomplishing this can also be found in this AIR.

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For purposes of discussion, fire protection consists of four basic divisions:

Prevention of Occurrence of Fire

Prevention of Spread of Fire

Fire Detection

Fixed Fire Extinguishing Systems



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1. FIRE PROTECTION FOR HELICOPTER GAS TURBINE POWERPLANT AND RELATED SYSTEMS INSTALLATIONS

1.1 General Discussion and Terms: In the concept of the gas turbine helicopter there are several fundamentals peculiar to its operational characteristics that should be set forth. It is emphasized that the concepts in this discussion have stemmed from experience on specific airplane-engine combinations in service and should therefore be carefully weighed in application to newer units. Operations show, however, definite trends as explained below such that the designer should be aware of their existence.

1.11 Typical Engine Hazards: To facilitate interpretation of the subsequent comments of this report, it is considered advisable to describe here the general failures and hazards considered basic to gas turbine engines.

1.111 Turbine: Experience to date has shown two distinct types of turbine failure to exist. One is thermodynamic in basic cause and the other mechanical.

A. Thermodynamic: The gas turbine operates only because of a large proportion of excess air (above that used for combustion) which dilutes and cools combustion temperatures to values which the turbine materials can tolerate. It is seen, therefore, that any cause factor which richens this ultimately very lean cycle will overheat the turbine. The type of failure resulting from turbine overheat depends upon the magnitude of the temperature rise and the rate of temperature rise. In case of a relatively moderate overtemperature, the blades will begin to melt at the tips and rapidly burn down toward the base, the molten metal being carried away by the exhaust gas.

The shortening of the blades results in a rapid loss of thrust and a rapid increase in the quantity and length of the flame. If the temperature rise is sudden and severe, as it would be in case of rapid ice accumulation on inlet screens and inlet guide vanes, for example, the blades may be severed by the flame, resulting in the outer 2/3 to 3/4 of all blades (red hot) being thrown outward tangential to the turbine and in an area lying within a few degrees of the plane of the turbine wheel. This type of failure may result in complete or partial severance of the tailcone and possible penetration of helicopter structure, tanks, controls or equipment located near the plane of the wheel. Careful thought should be given to the specific cause factors possible on a given helicopter.

Ice, controls which permit either compressor stall or excess fuel, or excess air bleed or leakage can cause this type of failure.

B. Mechanical: Occasionally, one or two blades of a single stage turbine will fracture and/or be "thrown". Normally, these do not penetrate parallel to the turbine plane but are restrained by the housing and penetrate at angles aft of this, if at all. Tail pipe puncture is usually the worst that happens which creates an emergency overheat condition. The engine usually becomes noticeably rough but operational under reduced power. Failures of forward stages of multi-stage turbines would probably be much more severe and cause fairly violent mechanical damage if not complete stripping of all stages, due to pieces of blade causing interference between stator and rotor blades. In case of such extensive damage, the structural integrity of the turbine housing may become questionable. It is noted that mechanical failures of the wheel itself rarely occur.

1.112 Compressor: Compressor case penetration by failed blades is very unlikely in high compression ratio engines due to the inherently strong case design. In installations with low compression ratios, however, case penetration should be considered as a possible fire cause factor, and lines and components containing flammable fluids should be located so as to minimize the hazard of damage by penetrating parts.

1.113 Tailpipe: On some engines, a high flow of fuel through a maladjusted fuel nozzle will cause burn-through of the tailpipe at a spot downstream of the fuel nozzle.

- 1.114 Engine Fires: Burning fluid will occasionally run out through the exhaust pipe. Positive provisions should be made either to let the fluid run free and clear of the airplane to the ground or to trap and drain it overboard. Operating procedures, proper fluid drainage and prevention of static oil leakage are best ways to prevent or minimize such fires.
- 1.115 Burner-Can Burn-Through: Under certain circumstances, internal engine damage can lead to burner-can burn-through. Because of the inability of standard firewall materials to withstand the flame for more than a short time, consideration should be given to other means to protect against such burn-through.
- 1.12 Terms and Definitions: Terms which must be defined to clarify their usage herein are the following:
- 1.121 Fireproof: A material which will withstand heat as well as or better than steel which will withstand 2000° F (1093° C) for 15 minutes and still fulfill its design purpose. When applied to materials and parts used to confine fires within designated fire zones, "fireproof" means that the material or part will perform this function under the most severe conditions and duration of fire likely to occur in such zones. Example: Transverse engine fire wall, which resists 2000° F (1093° C) flame for 15 minutes. (See Note of 1.122)
- 1.122 Fire Resistant: When applied to sheet or structural members, "fire resistant" describes a material which will withstand heat as well as or better than aluminum alloy in dimensions appropriate for the purpose for which it is used. When applied to fluid-carrying lines, other flammable fluid system components, wiring, air ducts, fittings and power plant controls, this term refers to a line and fitting assembly, component, wiring, duct or controls which will perform the intended functions under the heat and other conditions likely to occur at the particular location. An example: Fire resistant hose which will resist 2000° F (1093° C) flame for 5 minutes (See Note).
- Note: A test procedure to determine the minimum safe limits is presented in Reference 5.
- 1.123 Flame Resistant: Materials which will not support combustion to the point of propagating a flame beyond safe limits after removal of the ignition source.
- 1.124 Flash Resistant: Materials which will not burn violently when ignited.
- 1.125 Flammable: Solids, liquids, or gases which will ignite readily or explode. A percent nonflammable method applicable to fluids (aviation gasoline, kerosene, standard hydraulic fluid, lubricating oils, etc.) that are miscible with hexachlorobutadiene is presented in Reference 6.
- 1.126 Compartmentation: The process of isolating components or areas from each other or from other items or environments with which they would be hazardous in combination.
- 1.127 Ventilation Stop: An isolating bulkhead which is substantially vapor and liquid tight, for the purpose of controlling ventilation and liquid paths. Where this barrier has also the purpose of preventing rapid travel of a fire over wide areas of the helicopter, the ventilation stop should be at least fire resistant.
- 1.13 Zones and Zone Classification:
- 1.131 Combustible Zone: A helicopter compartment containing equipment from which leakage of combustible fluids or vapors is not abnormal. Example: Fuel cell bay.
- 1.132 Ignition Zone: A helicopter compartment containing equipment, structure or environment, which is normally an ignition source. Example: Inverter compartment.
- 1.133 Possible Fire Zone: A region in which an ignition source, together with combustibles, combustible fluid line leakage, or combustible mixtures, may exist at some time during airplane operation. The possible ignition source or combustibles might be contained within the region, or might enter the region from an external location during an emergency. At least the following sections, areas, or compartments should be considered to determine their possible hazards:

A. Engine Compartments

1. Engine Power Sections: This section includes burner, turbine and tailpipe.
2. Engine Compressor and Accessory Sections: This section includes the engine accessories. It may be the compressor compartment or other compartment such as a bullet-shaped housing in the engine front face.
3. Complete Power Plant Compartments: These are compartments in which no isolation is provided between the engine power section and the accessory section.

B. Auxiliary Power Plant Installation Sections.

C. Combustion Heater Installation Sections.

D. Other Regions Equally Hazardous from the Standpoint of Fire Possibilities.

1.134 Fire Zone: A "Possible Fire Zone" which has been recognized and treated as a region which requires fire detecting and, in most cases, extinguishing equipment and a high degree of inherent fire resistance.

1.135 Designated Fire Zones: Designated fire zones are:

- A. The compressor and accessory sections of turbine engines; and
- B. The combustor, turbine, and tailpipe sections of turbine engine installations except sections that do not contain lines and components carrying flammable fluids or gases and are isolated from the designated fire zone prescribed in subparagraph (A) of this paragraph by a firewall that meets 1.311A.
- C. An auxiliary power unit compartment.
- D. Any fuel-burning heater and other combustion equipment installation.

1.2 Prevention of Occurrence of Fire:

1.21 General Rules: Note: (E) denotes engine mfr. responsibility/interest. Although engine fire resistance requirements will have been met for military qualification/civil certification, noted paragraphs are marked for convenient review by engine manufacturers.

1.211 Design:

(E) A. Flammable Fluids: (per paragraph 29.1185, Reference 3)

1. No tank or reservoir that is part of a system containing flammable fluids or gases should be in a designated fire zone unless the fluid contained, the design of the system, the materials used in the tank and its supports, the shutoff means, and the connections, lines, and controls provide a degree of safety equal to that which would exist if the tank or reservoir were outside such a zone.
2. Each fuel tank should be isolated from the engines by a firewall or shroud.
3. There should be at least one-half inch (12.7 mm) of clear airspace between each tank or reservoir and each firewall or shroud isolating a designated fire zone, unless equivalent means are used to prevent heat transfer from the fire zone to the flammable fluid.

4. Absorbent material close to flammable fluid system components that might leak should be covered or treated to prevent the absorption of hazardous quantities of fluids.
 5. Design should be per References 7A, B, and C.
- B. Compartmentation: Separate and isolate combustibles from sources of ignition. In defining the application of this rule, any single potential failure of any equipment item (such as a leak in a fuel line connection, or burning out an electric motor) should be considered as a realistic basis under which the isolation principle should be met. It is desirable to govern the pressure of any ignition zone above that of an adjacent combustible zone because it compensates for the lack of perfect sealing which is normal after reasonable maintenance and service. Particular consideration should be given in the design of the compartment to preventing explosive ignitions associated with low ventilation and a time lapse between the leakage of a combustible and the ignition occurring. This condition can occur when the compartment environmental temperatures are just sufficient to cause ignition; the ignition occurs as a result of transient flight or engine operations interrupting the compartment ventilation, or an ignition source being separated and located downstream from combustible sources without airtight isolation between.
- C. Drainage: Combustible fluids and vapors should be prevented from accumulating by providing drain holes and/or lines in all compartments with possible combustible leakage. Minimum drain angles should be greater than 5 deg throughout the normal range of flight and ground conditions. Care should be taken to assure that pressure differentials across drainage provisions do not prevent their function. Example: An engine burner compartment using a tailpipe ejector pump for cooling may be at sufficient suction that the drains will not function. Drainage paths should be examined to determine that combustible fluids or vapors cannot re-enter into any compartment of the helicopter. Care should be exercised to prevent drained fluids from being drawn back into a tailpipe compartment being cooled by an ejector pump. Careful positioning of drain points vs. inlets and use of skin sealing will render impingement harmless. Drain discharge should not create a hazardous condition when in contact with exhaust gases under any condition of airplane maneuvering.
- D. Drain Lines: Drain lines should extend below the exterior surfaces when practical and be sealed at the surface to prevent a return of vapor or fluid into the compartment. Use of manifolded drains should be avoided. In cases where manifolding is necessary, pressure differentials in drained compartments or equipment, and ability to identify drained fluids should be carefully considered. Care should be exercised to assure that drained and manifolded fluids are compatible. When drains are manifolded, the manifolds should be sized to accommodate the total of the maximum individual drains contributing to the manifold.
- (E) E. Leakage: Tanks, equipment and lines containing combustible fluids should be located with the point of view in mind that leakage will sometime occur, and fire must not result. They should, therefore, be located remote from or below ignition sources, or isolated by compartmentation. If it is necessary to locate a fuel tank immediately adjacent to a firewall, a ventilated air space of at least 1 in. (25.4 mm) should be provided between the tank and the firewall. Drainage paths should be included to provide clearance from exhaust. Do not permit re-entry of drained fluids.
- F. Component Location: Combustible fluids tend to collect in the bottoms of compartments, so it is desirable to keep exhaust lines and other ignition sources as high within each compartment as practical. Combustible fluid lines and equipment should be located on the opposite side of a compartment from electric equipment and wiring, whenever possible. Combustible fluid lines should be kept to a minimum in the burner and turbine section.

- G. Engine Compartmentation: Isolation of areas of potential combustible leakage from hot portions of the engine, which can be ignition sources, should be employed whenever possible.
- H. Cooling: In combination with the isolation principles of "G" above, it can be seen that the cooling and drainage provisions of adjacent compartments with potential combustible leakage and potential ignition sources respectively should be carefully separated. If much stressed aluminum structure is used, relatively large cooling air flows are required.* Inlets for the aft compartment should be carefully separated from all outlet flow or drainage from compartments ahead.
1. Uniflow: Provisions for pumping air flow in any one predetermined direction through a compartment under all operating conditions can be made. Either tailpipe or compressor bleed ejector pumps can do this. Such uniflow cooling provides a high degree of safety with minimum complexity of detector and extinguisher provisions, since combustible sources can be located very near the air flow exits and therefore pumped overboard. In addition, for a small compartment, detectors need only be located in the exit air flow path, or, for a larger compartment, downstream of the hazard. Fire extinguisher locations would naturally be at cooling air flow entrances.
 2. Reverse Airflow: It is possible to use configurations in which cooling air is taken from the engine inlet duct. This provides reversed air flow during ground running plus a condition of zero cooling air flow at a series of air speed-power combinations. Caution should be used to prevent excessive inlet air contamination by leaking combustibles to avoid cabin air contamination or possible flashback through the engine compressor. The conditions of zero cooling air flow (the result of a reversal of the relation between engine inlet duct pressure and ambient pressure), cause a span of cooling air flow velocities which would be insufficient to move an ignitable mixture across a heated surface with enough velocity to prevent spontaneous ignition. The duplication and complexity of both fire detector and extinguisher systems which will arise should also be considered.
- I. Engine Air Inlet: The inlet should be so located and designed as to minimize the effects of ice accumulation and entrance of foreign matter into the engine. Foreign objects can come from several sources. The main ones are loose fasteners and access doors in the duct, mislaid tools, etc., and foreign matter from runways, etc. Correctly designed screens, either permanent or movable, should be considered in cases where a long air inlet duct or an inlet with an opening close to the runway, in the ground attitude, is used. Screen installations should be designed such as to prevent icing and foreign object damage by virtue of their own design. Engine air inlets should be designed so that air cannot be drawn from a compartment with potential flammable leakage during any ground or flight phase. Low pressure in the air inlet ducts versus the pressures in adjacent compartments and ambient, during ground runs and low speeds, can cause ingestion of flammable leakage with resulting fire, explosion and engine stall.
- J. Compressor Bleed: Plumbing to extract and carry high pressure hot air through the helicopter should have first order integrity of all connections, weld assemblies, etc. In most cases, the ducting will run hotter than minimum spontaneous ignition temperature of combustibles and should be positioned and treated as an ignition source. Where possible, bleed air should be cooled prior to entering combustible compartments in the helicopter.
- K. Fuel Location Relative to Engine: Fuel should not be located immediately above the engine. The plane of the turbine should be avoided for as wide a lateral dimension as possible because this plane and aft can receive the penetrations of overheated bucket fragments which constitute an ignition source. If fuel must be located within these zones strategic armoring around the turbine is considered effective. (See par. 1.212G Turbine Armor).

* Consideration should also be given to use of suitable insulation such as Refrasil to reduce the need for large cooling air flows, thus lowering the potential for spreading fire. Such insulation should have suitable provisions for drainage of combustibles.

- (E) L. Oil Tanks, etc., Relative to Engine: It is considered that oil tanks, hydraulic reservoirs, lines, etc., should be kept as far as possible toward the front of the compressor compartment. Relative location of combustibles and potential ignition sources such as wiring is important to avoid fire in that all may be damaged simultaneously during a compressor failure.
- M. Exhaust Leakage: Effort should be made to minimize exhaust leakage. Size of connections, pressure, and relative motion make some leakage practically impossible to avoid, so it should be considered as existent in basic design. Deflectors may be employed to guide leaks away from components in the area.
- N. Exhaust Outlet: High pressure ratio nozzles peculiar to turbojets will create a high mass-flow hot blast which must not impinge on unprotected surfaces. As pressure ratio rises, the jet fans out to a wider effective area, so caution should be taken not to assume dimensional similarity to jet wake geometry experienced on low pressure ratio engines.
- O. Fuel Vent Configuration: Fuel vent systems should be designed so that fluids will not spill out during maneuvering. Actual ground tests should be conducted under conditions of maximum acceleration, deceleration, and 360 deg turns on a sharp radius. Flight test analysis should include consideration of maximum roll, climb and glide angle, yaw, and rotation of the airframe from normal altitude to these positions. External fuel tank installations equipped with vent valves having pressure relief provisions should be checked from spanwise accelerations to insure against spillage during high speed taxi turns.
- P. Fuel Vent Outlets: Fuel vent outlets should be so located and designed that solid fuel exiting from them cannot impinge on any airplane surface or be in a hazardous position relative to the engine exhaust. Malfunction or misuse of fuel transfer systems should not cause a high rate of fuel flow to be pumped out the vent.
- Q. Fuel Dump System: Fuel dumping systems should be designed so that fuel will not impinge on any airplane surface while being dumped. Ground inspection should be made frequently, to prove that lines are intact, and will not leak in the event they are used in flight. The fuel jettisoning system should be designed so that any reasonably probable single malfunction in the system will not result in a hazardous condition due to unsymmetrical jettisoning of, or inability to jettison fuel.
- R. Ventilation: Compartments with potential leakage of combustible fluids or vapors, and containing ignition sources, should be adequately ventilated. This ventilation should be designed to lean out combustible mixtures below the lower limits of flammability, minimize dwell time of combustibles on hot surfaces and reduce environmental temperatures. Fire zone ventilation should also be sufficient to provide unflow and prevent stagnant areas in an attempt to reduce combustible vapor buildup. Ventilation in all compartments with possible combustible leakage should be designed to prevent interruption or reversal by transient flight or engine operations. Where mixtures too rich to burn can be maintained in these compartments throughout the flight regimes, prevention of air circulation rather than ventilation may be employed.

Each designated fire zone should be ventilated to prevent the accumulation of flammable vapors.

No ventilation opening should be where it would allow the entry of flammable fluids, vapors, or flame from other zones.

Ventilation means should be arranged so that no discharged vapors will cause an additional fire hazard.

For category A rotorcraft,* there should be means to allow the crew to shut off the sources of forced ventilation in any fire zone (other than the engine power section of the powerplant compartment) unless the amount of extinguishing agent and the rate of discharge are based on the maximum airflow through that zone.

- (E) S. Hot Surfaces: Hot surface temperatures of equipment and lines located in areas of possible leakage of combustible fluids or vapors should be well below the autogenous ignition temperature of these fluids or vapors under any condition or normal operation or emergency.

- (E) T. Hot Gas: Ducts and equipment carrying hot gases or hot air should not be located in areas of possible leakage of combustible fluids or vapors, unless the gas or air temperature is well below the hot gas ignition temperature of these fluids or vapors under all normal and emergency conditions. If such location cannot be avoided, ignition should be prevented by a duct design of the highest leakproofness and reliability.

- (E) U. Electric Wire Routing: Wiring should be installed well above combustible fluid lines, where the presence of both items is necessary. Frequent supports are necessary to prevent a free end of a broken wire from touching fluid lines or tanks. Particular attention should be exerted in installation of wire runs to prevent hazardous conditions. Enough slack should be left in wire bundles to take into account airframe flexibility. Wire used in high temperature environment should be resistant to these high temperatures.

- (E) V. Electric Equipment: Electric system equipment should be examined critically for possible sources of ignition both under normal as well as on the ground operation and possible conditions of failure. In any zone such as a fuel tank where combustible fluid or vapor may occur in normal operation, any such equipment which might be an ignition source under normal operation or possible conditions of failure should be contained within an explosion-proof casing as defined by Ref. 8. In any zone where combustible fluid or vapor may occur only as a result of abnormal conditions such as leakage of a fuel line, equipment which might be an ignition source in normal operation should be contained within an explosion-proof casing or enclosed within a vapor-safe compartment. Resistors, shunts and other high-temperature electric equipment should be examined carefully for possible fire hazards when operating at their maximum temperature conditions. Arcing may occur between the external power plug and receptacle when connecting or disconnecting with ground power operating. No combustible fluids and vapors should be allowed to be present in the area of the receptacle prior to installing or removing the plug.

- (E) W. Lines and Ducts: Lines and ducts carrying combustible fluids or vapors, or hot air should be provided with bends or other expansion means to avoid rupture. Adequate support of fluid lines is essential to eliminate breakage due to vibration. Particular attention should be given to the spring of supports to dampen resonant vibration frequencies. The practice of supporting tubes from each other should be avoided. This practice introduces the possibility of fatigue failure because of the differences in vibration and expansion. When flexible lines are used, ample slack should be provided, if relative motion occurs between components. Below standard radii should be avoided on tubing to eliminate possible fatigue failure at bends. Lines and ducts carrying combustible fluids and vapors, or hot air should incorporate the most dependable type of connections available to prevent leakage. Nipples and hose clamps are not satisfactory where vibration, relative motion, axial loading, high temperatures, or high pressure exist. The combination of fire resistant hose with detachable end fittings using "B-Nuts" is questionable from a fire resistance standpoint, but seems to be the best current available configuration. The use of lightweight flange fittings is questioned in fire zones because of fire resistance and "sandwich" type connections (i.e., two flanged fittings gasketed to a bulkhead and held by through-bolts) should be used only with caution because of the leakage hazard.

* Category A Rotorcraft are transport rotorcraft certificated under FAR 29 and are capable of climb with one engine out.